Exhibition Hall 4A

CHILLVENTA 2014

Current and Future Low GWP Fluids for Commercial Refrigeration Applications

Technical Programme

Topic / Agenda

Current and Future Low GWP Fluids for Commercial Refrigeration Applications

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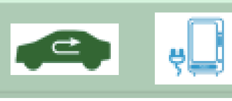
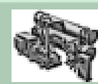
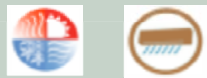
- **Introduction**
- **Evaluation and Handling Issues for Blends of refrigerants**
  - Compressor Calorimeter
  - Fractionation of blends during leak events
- **System Evaluations of R-404A Replacements**
  - Non-Flammable options (N-40 / R448A)
  - Mild-Flammable options (L-40)
  - Overall Environmental Impact
- **Concluding Remarks**

Refrigerants: Reduced/Lowest GWP Options

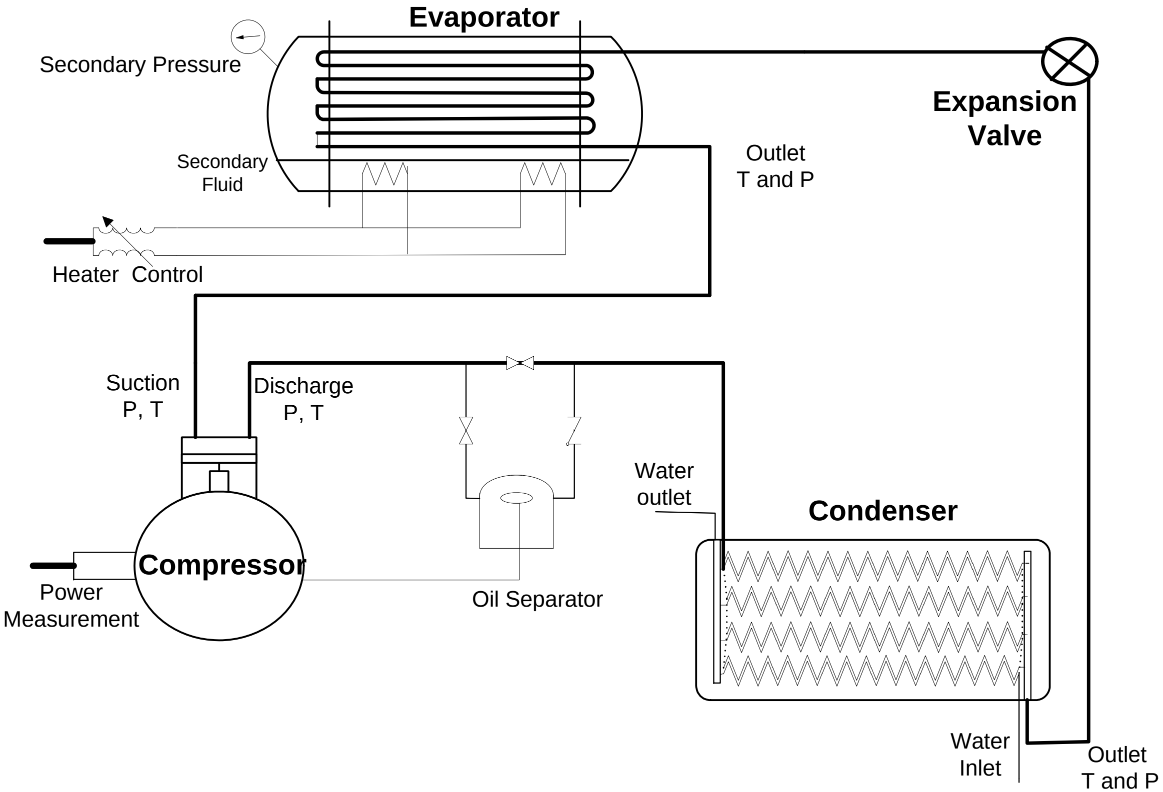
HFO Molecules (Ultra-Low GWP)

Examples of Applications	Current Product	Non-Flammable (ASHRAE A1)	Mildly Flammable (ASHRAE A2L)	Application Icons
MAC, Vending, Refrigerators	HFC-134a GWP-1430		Solstice® yf GWP<1 R-1234 yf	
Chillers, Cascade, Refrigerators			Solstice® ze GWP<1 R-1234 ze	
Centrifugal Chillers	R-123 GWP-77	Solstice® zd GWP 1		

HFO Blends (Low GWP)

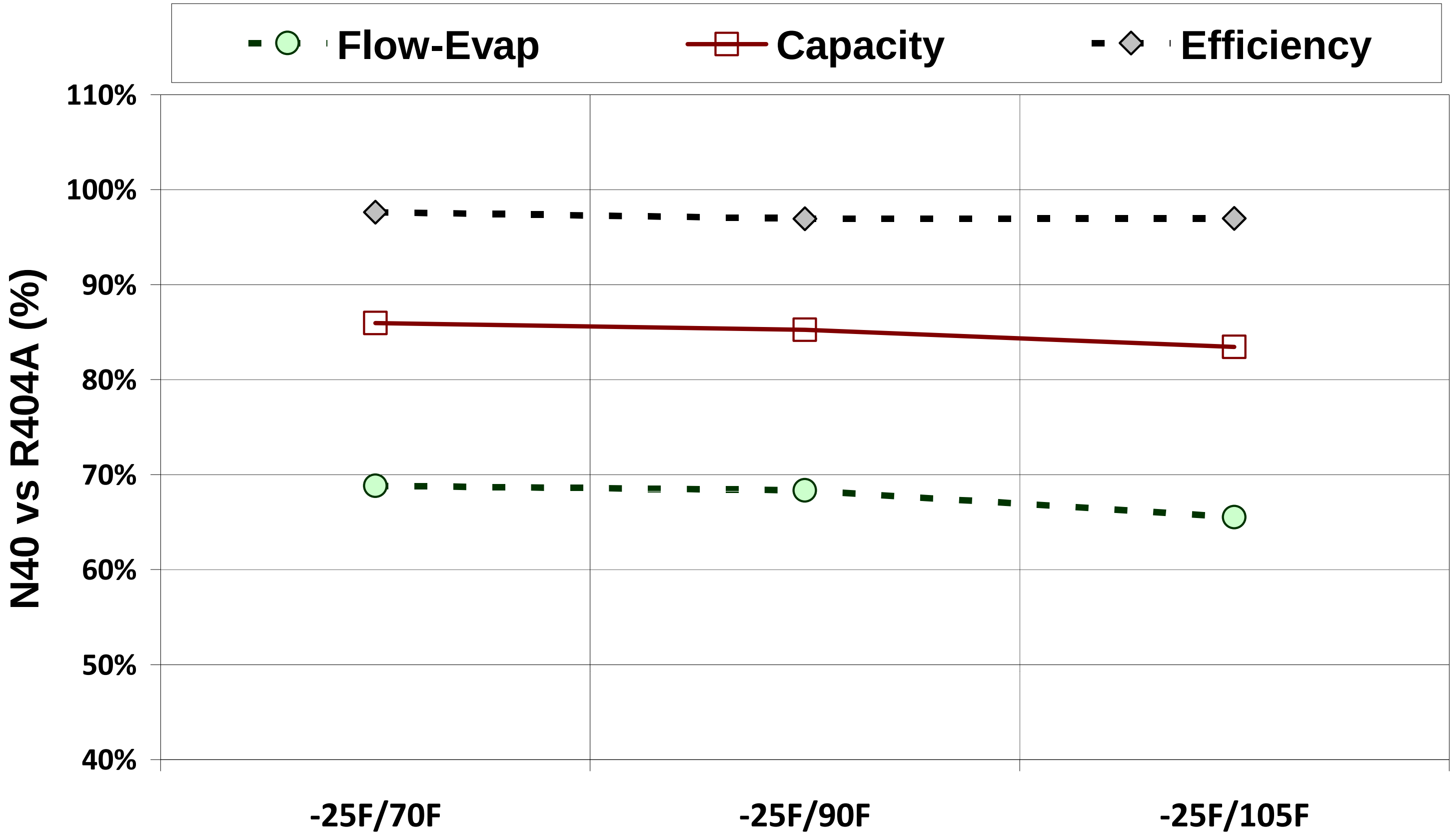
Examples of Applications	Current Products	Solstice N Series Reduced GWP Option Non-Flammable (ASHRAE A1)	Solstice L Series Lowest GWP Option Mildly Flammable (ASHRAE A2L)	Application Icons
Chillers, Medium Temp Refrigeration	HFC-134a GWP-1430	N-13 GWP ~600 (R-450A)		
Stationary A/C, Refrigeration	HCFC-22 GWP-1810	N-20 GWP <1000	L-20 GWP <300 (R-444B)	
Low-and Med-Temp Refrigeration	R-404A GWP-3922	N-40 GWP ~1380 (R-448A)	HDR110 GWP <150	
Stationary A/C Applications	R-410A GWP-2088		L-41 GWP <600 (R-447A)	

Compressor Evaluations



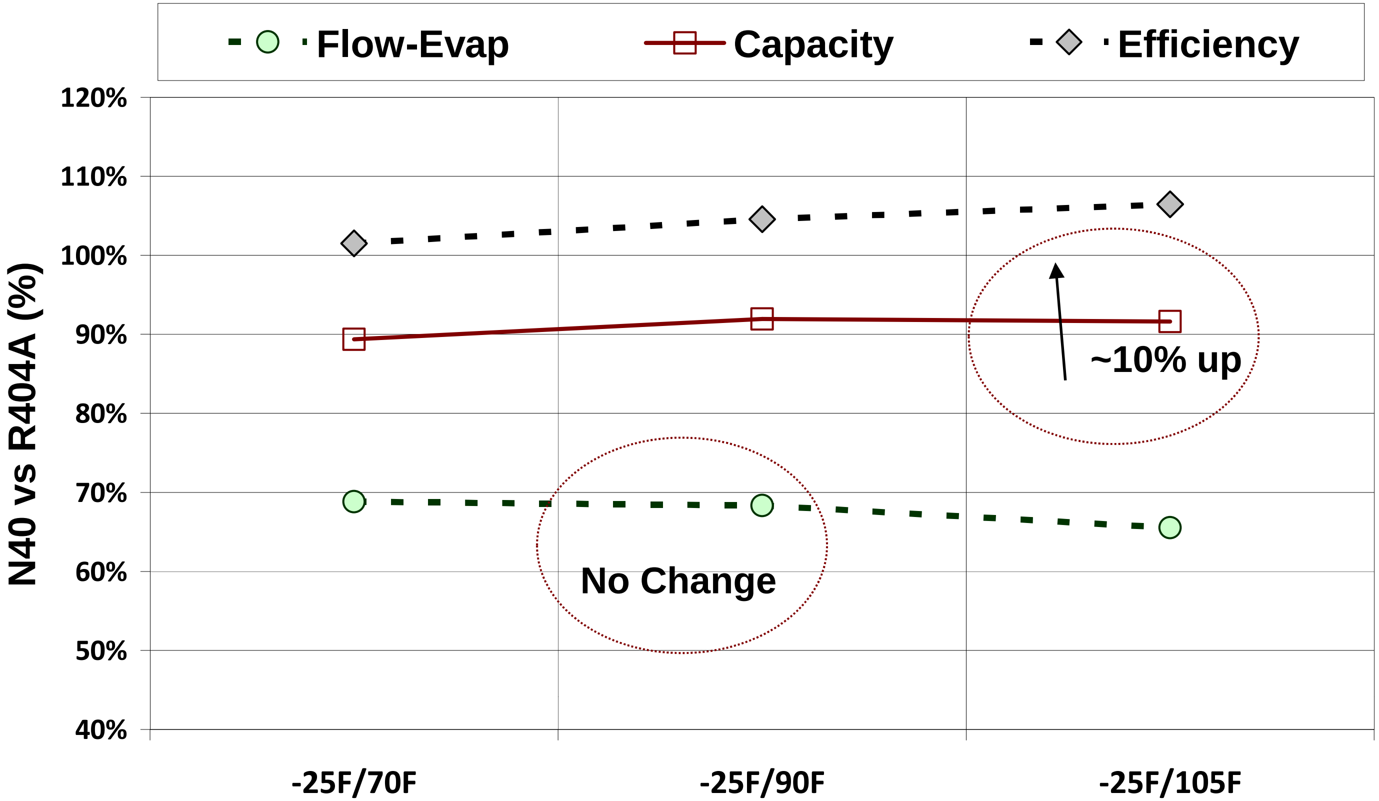
- Employed a fully-instrumented 50k BTUH Secondary-Fluid Calorimeter.
- Tested a 38.3 kBTUH semihermetic compressor, using R404A, R407F and N-40.
- Operating Conditions as required by AHRI standard 540:
  - Evaporating temperatures of -40ºF and -25ºF; Condensing temperatures of 70ºF, 90°F, and 105ºF
  - Ambient temperature of 95ºF, saturated liquid at the inlet of expansion device.
  - Used “Dew” pressures and a fixed value of 65ºF gas temperature at the suction.

N-40 (R-448A) vs R404A: Standard Calorimeter Conditions



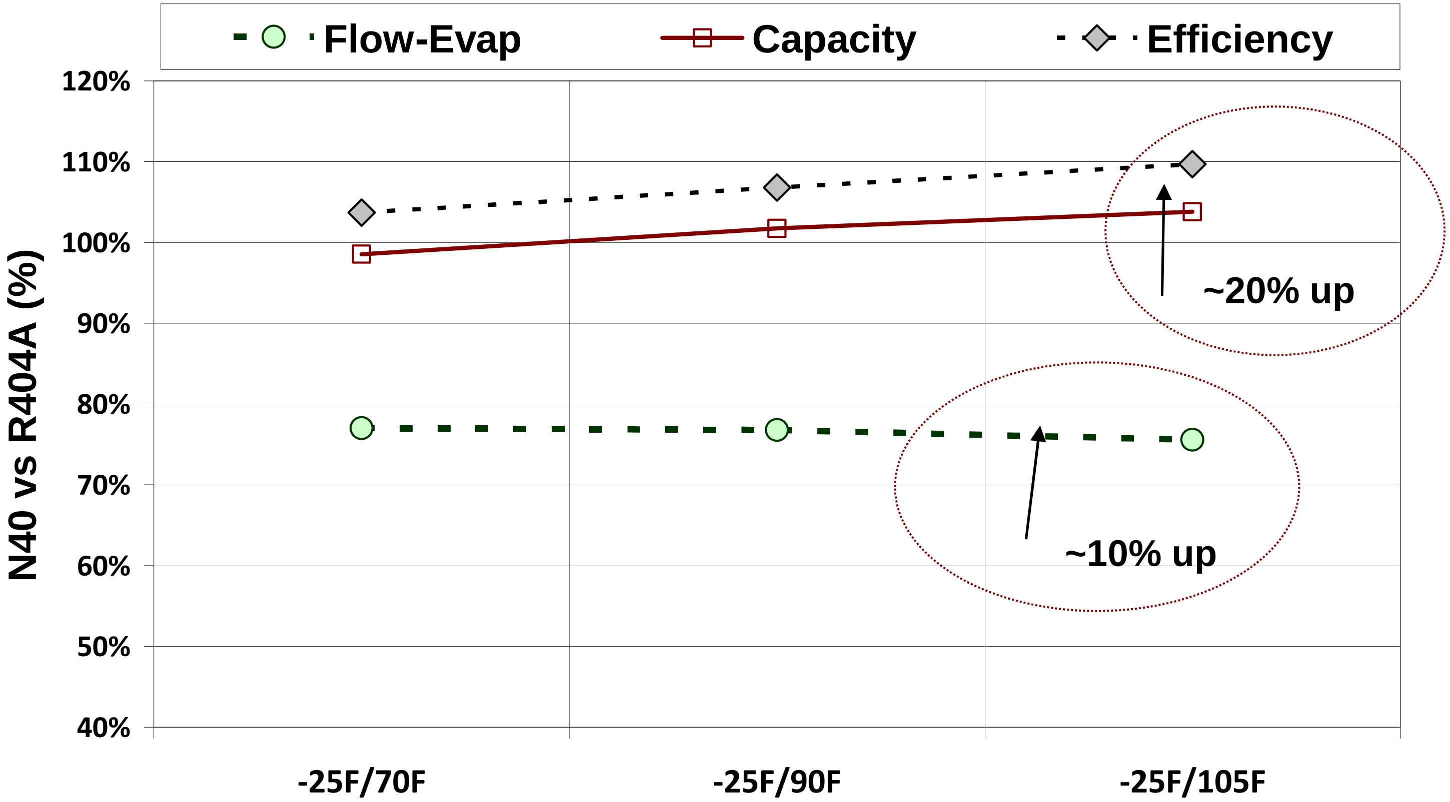
- When evaluated using Dew pressures and 65ºF suction gas temperature, N40 shows low capacity (84% to 86% relative to R404A) and similar efficiency to R404A.
- The use of a fixed suction gas temperature (65ºF) would also affect compressor efficiency as actual suction temperatures are significant lower.

N-40 (R-448A) vs R404A: Useful Cooling for 10ºF Superheat



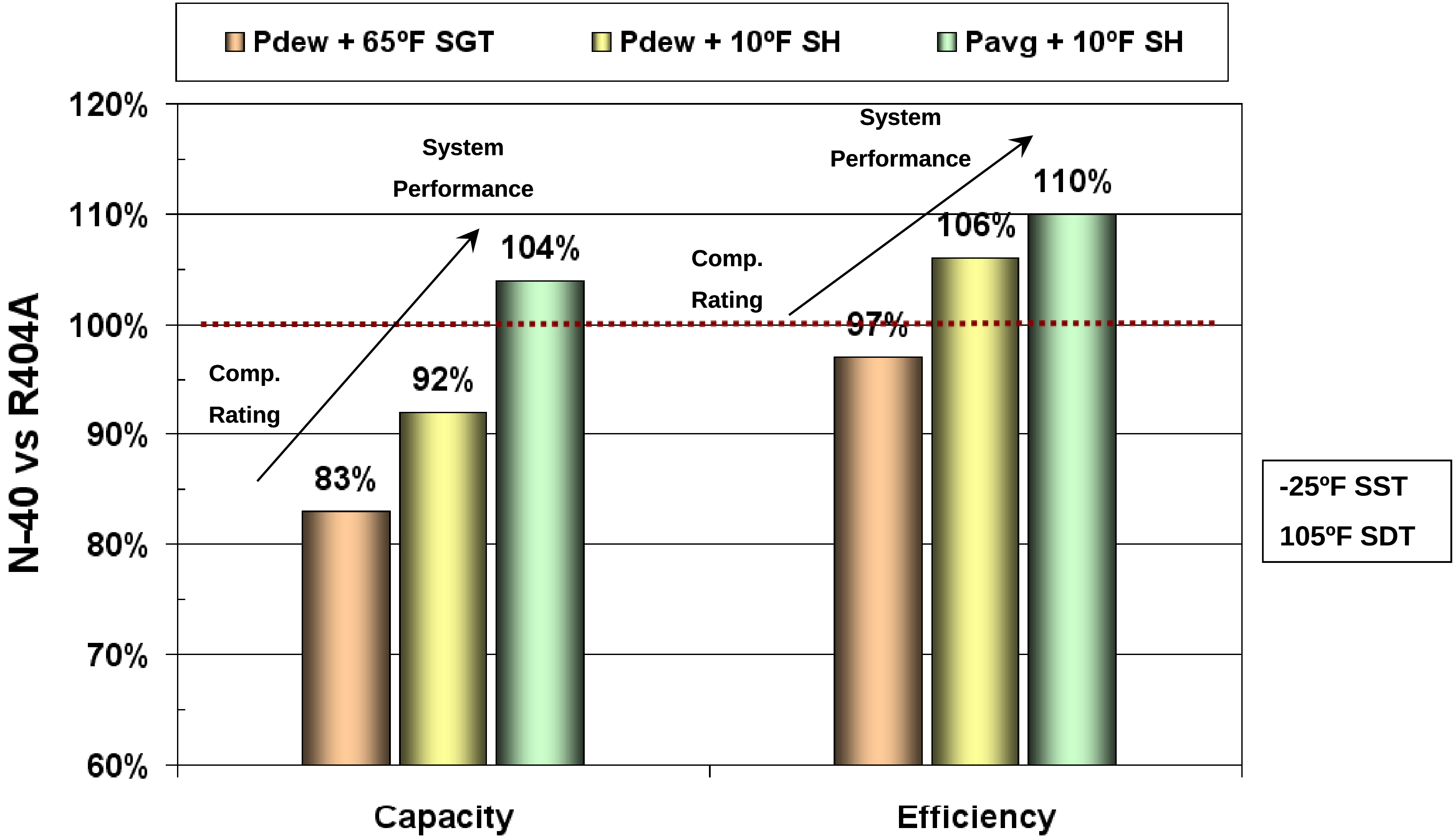
- Corrected the cooling capacity to use actual superheat at evaporator outlet of 10ºF.
- Refrigerants with high contents of R125 (like R404A) have low latent heat and benefit from calculating the refrigerating effect at 65ºF suction temperature.
- Effects are as high as 10% in both capacity and efficiency.

N-40 (R-448A) vs R404A: Using 10ºF SH + Average Pressures



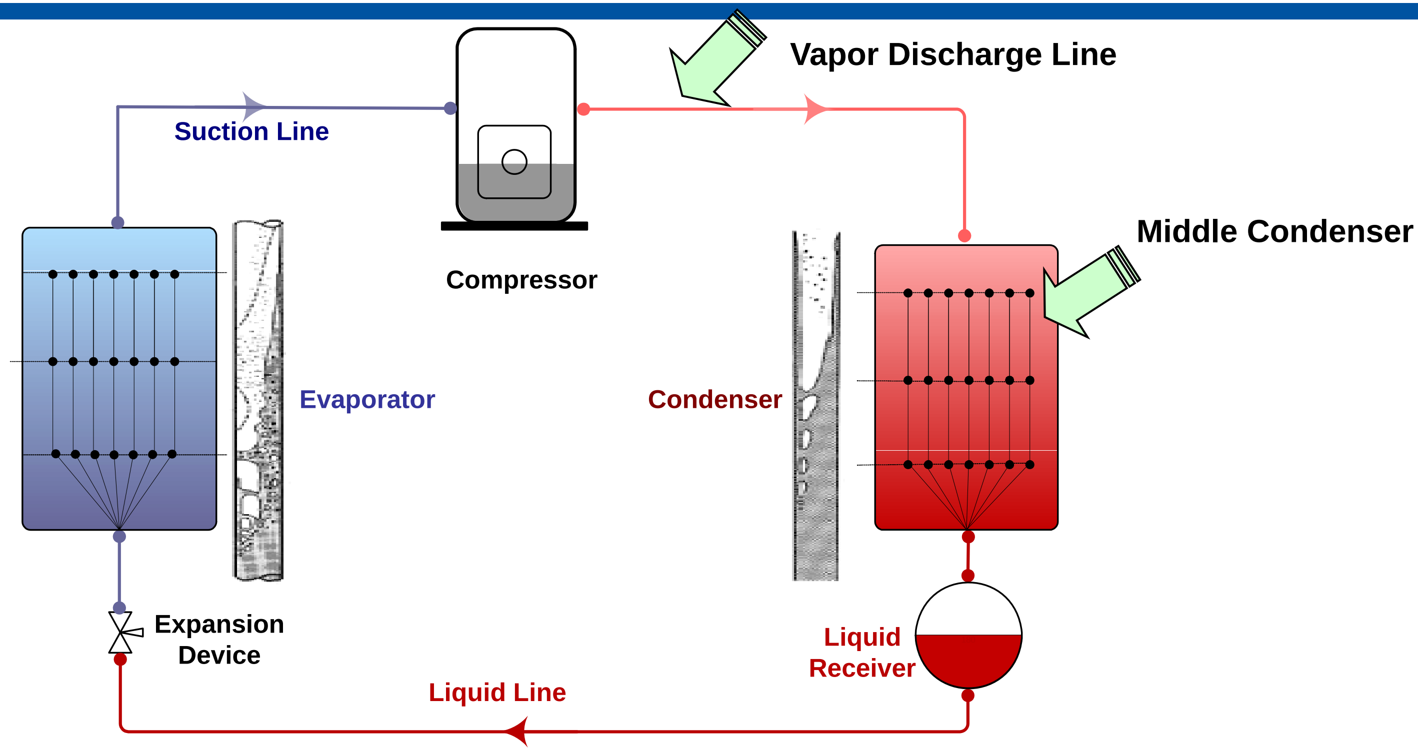
- The use of Dew pressures penalize blends with glide in compressor calorimeter evaluations
- Using average pressure and realistic degree of superheat results in capacities and efficiencies similar to values obtained in tests of refrigeration systems.
- Effects are as high as 20% when both average pressures and useful superheat (10ºF) are used.
- Other effects of testing compressor at high suction temperatures (volumetric and isentropic efficiencies) should also be investigated.

Learnings from Compressor Calorimeter Evaluations



Compressor rating data should be used with caution for blends with glide.
Actual system performance can be significantly different.
Data suggests review of Testing Conditions in AHRI Standard 540

Fractionation of Blends during Leak Events



- **Test System/Operating Conditions:**
  - 1-Ton walk-in cooler/freezer system (semi-hermetic compressor, liquid receiver).
  - System charged with 19lb of R407F (30% R32, 30% R125, 40% R134a) and 2200ml of POE oil (ISO 32)
  - Box temp of -15°F; Outdoor ambient temperature varying from 50°F to 60°F.
- **Leak events were simulated using a 0.1mm ID orifice and two scenarios:**
  - **System ON**: 1) Vapor discharge line, 2) Middle of condenser (liquid-vapor)
  - **System OFF**: in the middle of the condenser (vapor while system OFF)
  - Small refrigerant samples (4g each) were analyzed unsing Gas Chromatography.

System ON: Vapor leak from the Discharge Line

	Description	Start	Sample 1	Sample 2	Sample 3
	Time (hours)	0	8.2	23.7	26.7
	Charge (%)	100%	94%	84%	82%
Composition	R32	30.8%	31.3%	31.9%	31.8%
	R125	29.3%	29.5%	29.8%	30.0%
	R134a	39.9%	39.2%	38.3%	38.2%
Performance before top-off	Capacity (%)	100%	101%	102%	102%
	COP (%)	100%	100%	100%	100%
Performance after top-off	Capacity (%)	N/A	101%	101%	101%
	COP (%)	N/A	100%	100%	100%

- Took small samples (4g each) from the liquid line at different times.
- Leak event carried out until losing "liquid seal" in the sight glass after the receiver.
- Leaks from vapor discharge line do not seem to cause significant fractionation.
  - Since leak is coming from the vapor line, the refrigerant leaks is at the circulating composition
  - Overall, composition changes are small and within typical tolerances (±2%)
  - Performance remains unchanged even before topping-off (completing the charge with the nominal composition) the system.

System ON: Two-phase leak from the Condenser

	Description	Start	Sample 1	Sample 2	Sample 3
	Time (hours)	0	5.5	22.1	28.2
	Charge (%)	100%	94%	78%	72%
Composition	R32	30.8%	29.5%	28.3%	27.7%
	R125	29.5%	28.7%	28.0%	27.7%
	R134a	39.8%	41.8%	43.7%	44.6%
Performance before top-off	Capacity	100%	98%	96%	95%
	COP	100%	100%	100%	100%
Performance after top-off	Capacity (%)	N/A	98%	97%	96%
	COP (%)	N/A	100%	100%	100%

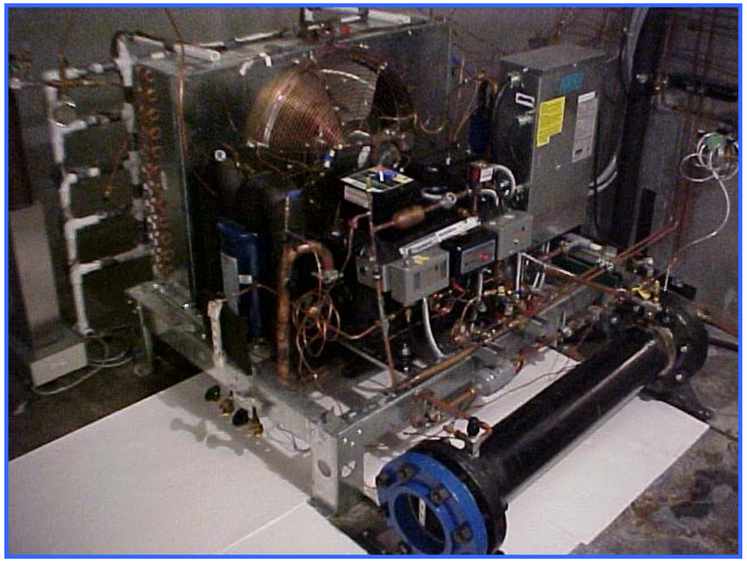
- Took small samples (4g each) from the liquid line at different times.
- Leak event carried out until losing "liquid seal" in the sight glass after the receiver.
- Two-phase leaks seem to cause slightly larger changes in composition.
  - For 20% charge loss, overall composition is still within typical tolerances (±2%)
  - Changes in performances within experimental error (±5%)
  - If the charge is topped-off, composition and performance become even closer to original values.

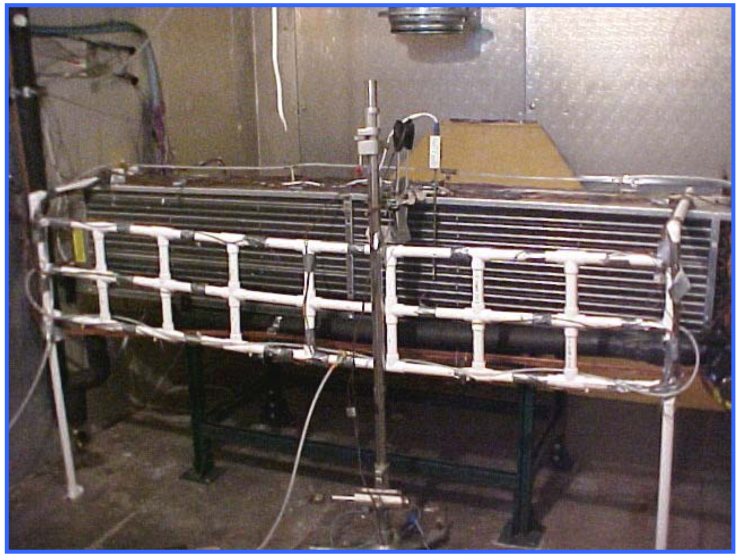
System OFF: Slow Vapor leaks

	Description	Start	Sample 1	Sample 2
	Time (hours)	0	20.3	37.4
	Charge (%)	100%	79%	62%
Composition	R32	30.0%	29.2%	27.7%
	R125	30.1%	29.8%	28.7%
	R134a	39.9%	41.1%	43.6%
Performance before top-off	Capacity	99%	99%	96%
	COP	100%	100%	100%
Performance after top-off	Capacity (%)	N/A	99%	98%
	COP (%)	N/A	100%	100%

- A slow vapor leak with the system OFF is known as the “worst case” scenario.
- Followed special procedure with these typical steps:
  - Turned system OFF and allowed 4 days to settle before starting leak.
  - Started leak event which lasted between 17h to 20h.
  - Stop leak and turn system ON to take sample from the liquid line.
- For 20% charge loss, composition is still within typical tolerances ($\pm$2%)
- For the largest charge loss, performances is still within experimental error ($\pm$5%)
- After top-off, composition and performance become even closer to original values.

Refrigeration System Test Apparatus

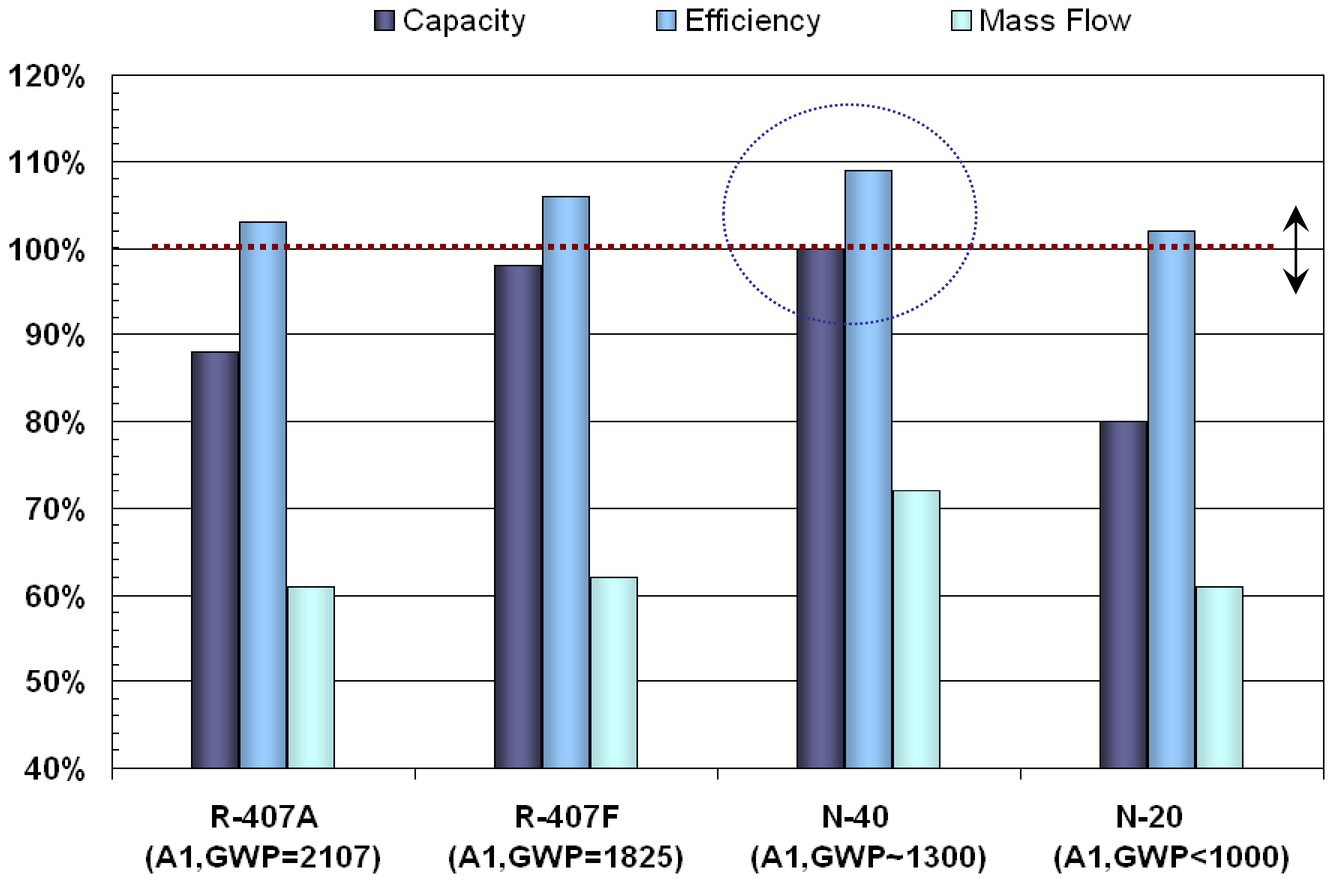




- 2.2 kW semi-hermetic condensing unit with evaporator for walk-in freezer/cooler.
- Used long connecting lines (typical of supermarkets), taking into account suction pressure drop and temperature rise effects.
- **Operating Conditions:**
  - Low temperature:
    - -15°F and 0°F Box Temperature; 55°F, 75ºF and 95°F Outdoor Ambient Temperature
  - Medium Temperature:
    - 35°F and 50°F Box Temperature; 55°F, 75ºF and 95°F Outdoor Ambient Temperature

Non-Flammables: Performance at Low Temperature

<u>**Low Temperature conditions: 95ºF Outdoor, -15ºF Box**</u>



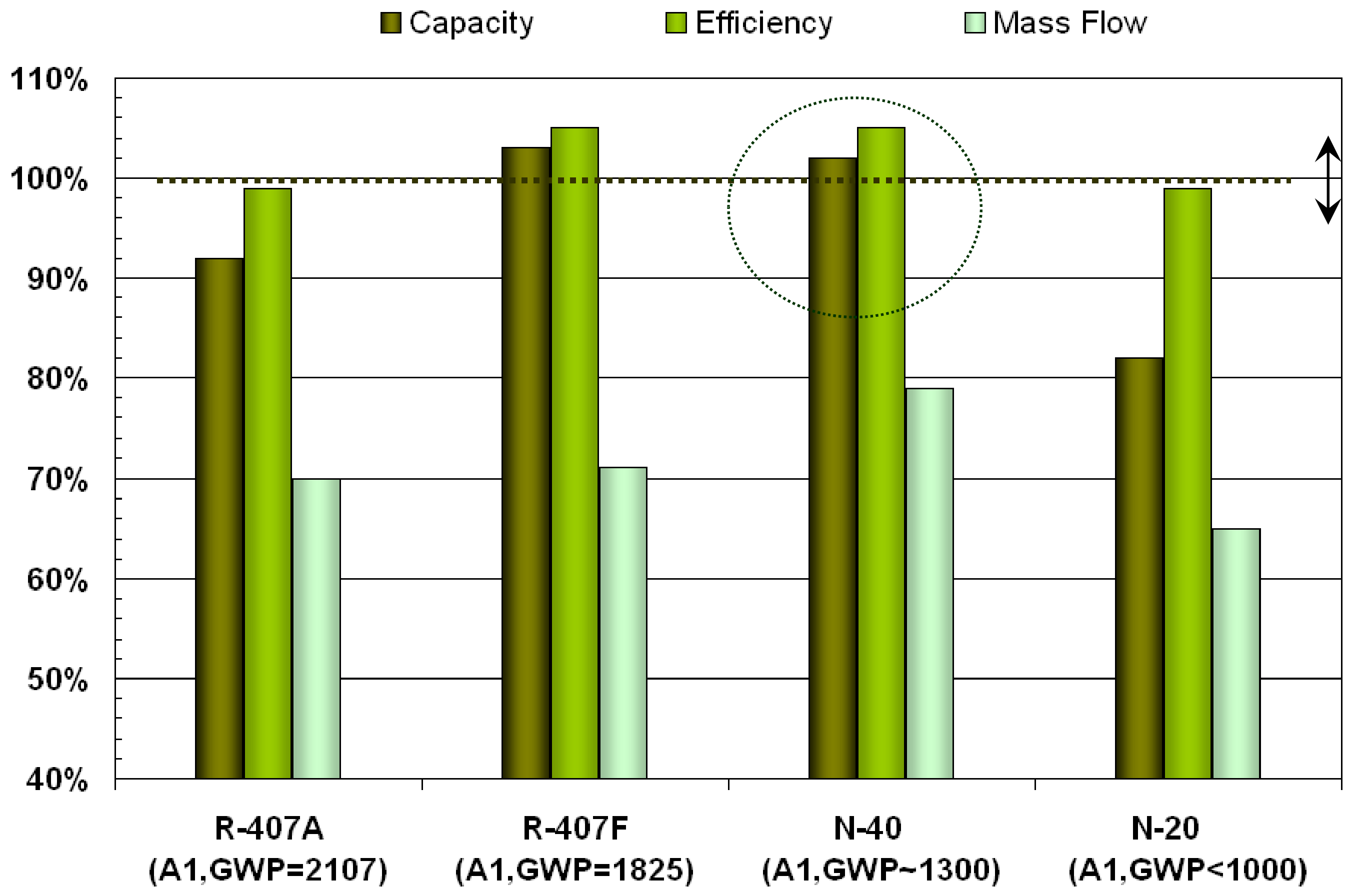
Supermarket Freezer Cases (LT)

N-40 (R-448) performance in System evaluations match "corrected" Compressor data

Similar Results were obtained for commercially available R407F

Non-Flammables: Performance at Medium Temperature

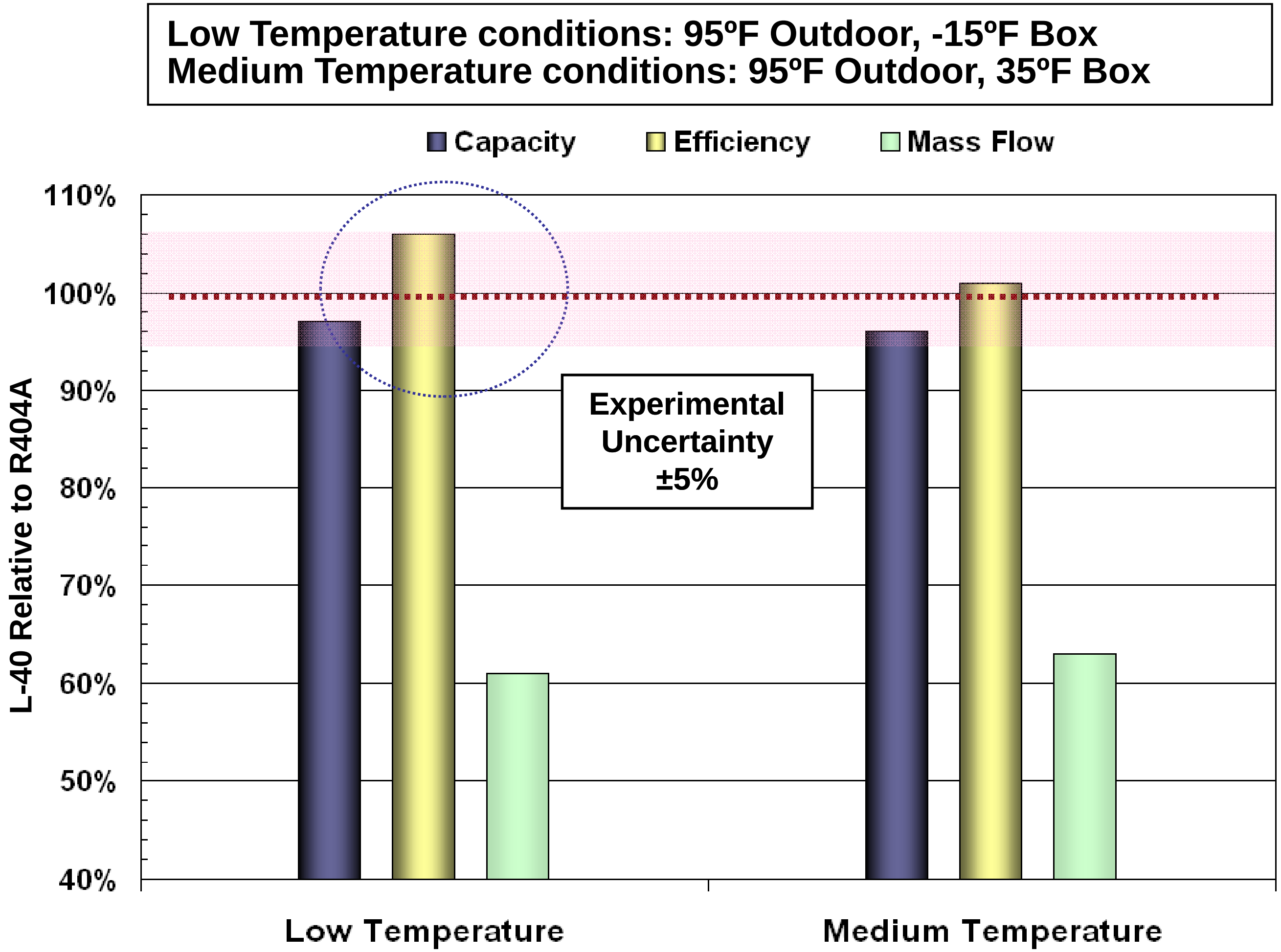
<u>Medium Temperature conditions: 95ºF Outdoor, 35ºF Box</u>



Supermarket/Deli Cases (MT)

Results for Medium Temperature Refrigeration are also similar
Overall, N-40 (R448A) provide excellent Energy Efficiency

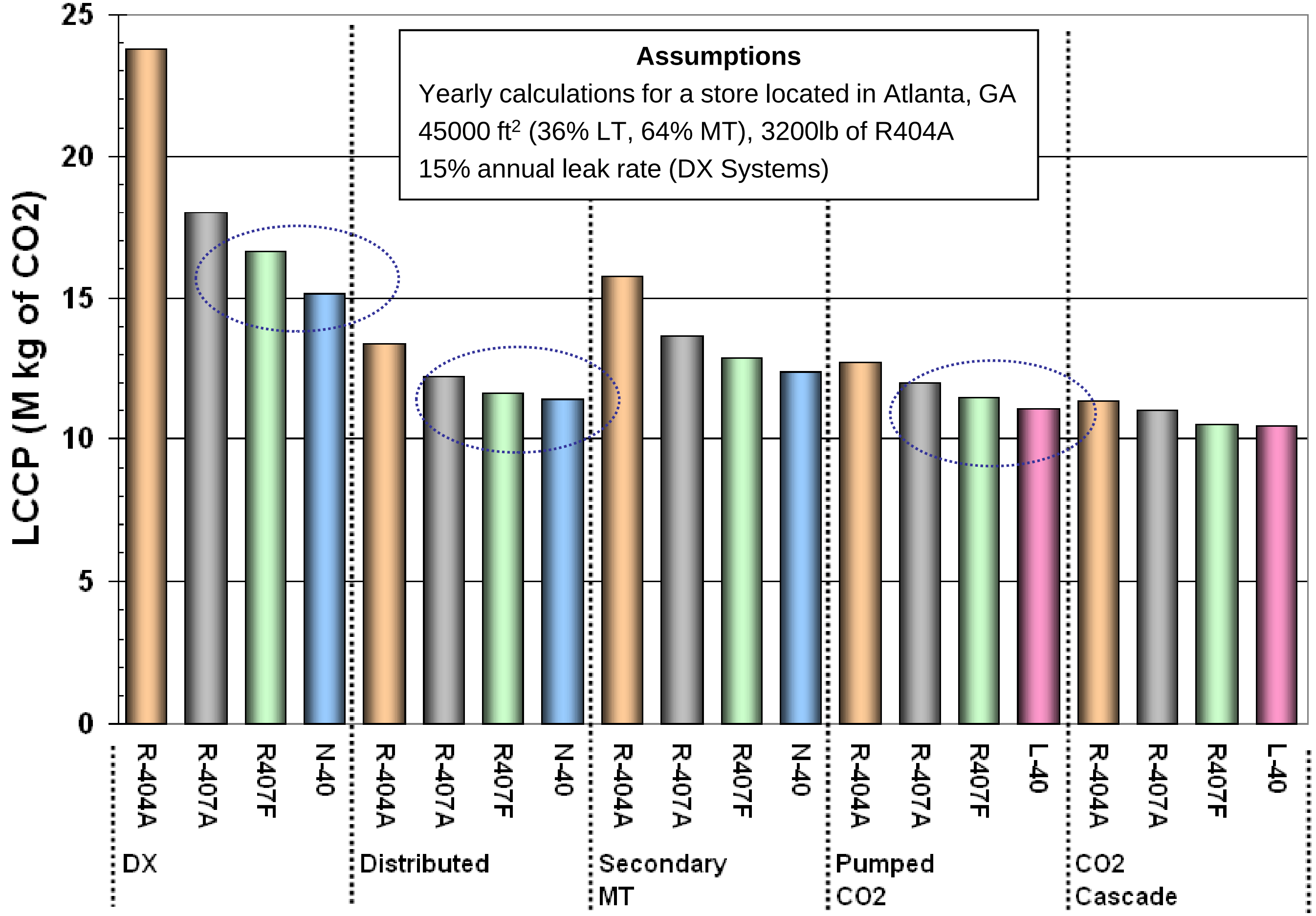
Mild Flammables: Performance



- GWP reduction of over 90% relative to R-404A drastically reduces direct emissions
- Superior energy efficiency relative to R-404A further reduces environmental impact.

L-40 can be used in the high stage of Cascade (with CO2) and Secondary-Fluid!

Environmental Impact - LCCP Analysis



- The use of N-40 (R-448A) and even R407F, allows considerable reduction of environmental impact when retrofitting existing systems (~50%).
- Among current DX technologies, distributed systems using N-40 (R-448A) produce environmental impact similar to more sophisticated technologies (cascade and pumped CO2).

Concluding Remarks

- **Evaluations of blends in compressor calorimeters show significant difference to actual system performance.**
  - Possible revisions of AHRI standard 540 for compressor calorimeter testing suggested

- **Fractionation Study under realistic "leak" events shows little impact on actual system performance.**
  - Effects of actual working conditions (turbulence/mixing) and oil presence seem to attenuate composition change.

- **N-40 (R-448A) provides higher Energy-Efficiency with *Reduced-GWP***
  - Non-flammable (A1) allows use in existing systems that use R404A
  - LCCP analysis demonstrate that superior Energy-Efficiency and lower GWP (~1300) reduce the carbon footprint of current and future systems.

- **Further work is needed to fully explore these applications.**
  - Additional performance and "field" evaluations planned.
  - More detailed LCCP evaluations are also suggested.

Exhibition Hall 4A

THANK YOU

Questions?

Technical Programme